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Hull Material Selection for Replacement Patrol Boats - An Overview

Seref Aksu, Stuart Cannon, Craig Gardiner and Matthew Gudze

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Maritime Platforms Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

This technical note considers the main characteristics of steel, aluminium alloys and glass fibre-reinforced composite materials in relation to the selection of primary structure for patrol boat type platforms. It is not intended to recommend or rank the suitability of candidate materials, but rather to note the main properties of each material and outline some practical considerations in relation to the construction, maintenance and military operation of patrol boats constructed from these materials.

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Hull Material Selection for Replacement Patrol Boats- An Overview

Executive Summary

The main characteristics of steel, aluminium alloys and glass fibre-reinforced composite (GRP) materials have been outlined in relation to the construction, maintenance and military operation of a patrol boat type platform. In order to achieve the required capability and preparedness of a platform constructed in these materials it is most important that appropriate inspection, maintenance and repair procedures be implemented. Such procedures are well established for steel vessels operating in the Royal Australian Navy (RAN). Appropriate inspection, maintenance and repair procedures have also been implemented to a lesser degree for RAN vessels constructed in aluminium alloy (HMAS Jervis Bay) and GRP (Minehunter Inshore (MHI) and Minehunter Coastal (MHC) fleets).

Some guidance is given on the comparative costs of a patrol boat craft constructed in each material. In this regard it is important to consider both the initial and operational costs and also the resale value of a platform.

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1. Introduction

The current Fremantle Class Patrol Boats have now exceeded their design life of 15 years and have already undergone a four-year life extension. In 1998 the government approved a further eight-year life extension to the vessels. This is now seen as a high-risk solution to meeting the Australian Defence Force's (ADF) needs. This is due to the current structural problems with the existing craft and the increase in time required for the maintenance periods. In November 1999 the Defence Capability Committee (DCC) endorsed a proposal to cancel the life extension project and to obtain a replacement vessel built to commercial standards.

There are many factors that remain undecided in replacing the current patrol boats. It is the intention of the Department of Defence to allow industry to develop a wide range of cost-effective solutions that will meet the functional requirement of a patrol boat. One of the major considerations for the design and build of a replacement patrol boat is the material of construction. Australian Industry currently has an excellent reputation in building military and commercial vessels out of the three major construction materials, ie steel, aluminium alloys and composites.

The aim of this technical note is to review the main characteristics of steel, aluminium alloys and glass fibre-reinforced composite (GRP) materials in relation to the selection of primary structure for patrol boat type platforms. It is not intended to recommend or rank the suitability of candidate materials, but rather to note the main properties of each material and outline some practical considerations in relation to the construction, maintenance and military operation of a craft constructed from these materials.

2. Material Properties of Steel, Aluminium Alloys and GRP Composites

2.1 Steel

There are many different grades of steel, each with its own characteristics and suitability for a particular application. Mild steel is the most commonly used and cheapest shipbuilding material. Advantages of steel may be listed as:

- Low cost
- Ductile under ambient conditions
- Virtually isotropic
- Easily formed and fabricated
- Easily obtained (low relative cost)
- Easily alloyed or heat treated for special operations

- Easily repaired
- Good fire resistance
- Behaviour is well understood.

Disadvantages of steel may be given as:

- Corrodes easily
- Has no lower fatigue limit for welded structures
- Heavy
- Brittle at low temperatures
- Magnetic

Due to these advantages, steel remains the most popular material for welded ship structures. However, one serious problem with steel is its tendency to corrode in a marine environment. Protective coatings may be used to defer the initiation of corrosion. Thus, the planning and execution of inspection, maintenance and repair of the hull structure will assume a high level of importance.

Mild steel has another particular disadvantage in that toughness is reduced and it can become brittle at low temperatures. Therefore, caution must be exercised if mild steel is to be used in any large structure that may be subject to relatively high rates of loading (for example collision or minor weapon impact) in cold conditions (Chalmers, 1988 and Chalmers, 1993). In extreme cases, even high seas may be enough to trigger brittle failure. Although replacement patrol boats are not planned to operate in extremely cold conditions, brittle fracture and high thermal stresses may still be of concern due to large temperature variations in the prescribed operational envelope of these vessels.

Various types of high strength steels exist and these are usually advocated in surface ships to reduce weight. However, high strength steel only provides greater strength. No advantage is provided in terms of stiffness. Strength of the replacement patrol boats, with a length of approximately 50 – 60 m, will be mostly determined by the adequacy of the local structure in terms of buckling of local plating and stiffeners, and not by the longitudinal hull girder strength. Therefore, it is expected that no substantial weight savings will be gained by the use of high strength steels.

There are four grades of normal strength steels used in shipbuilding. These are designated by the alloying composition and the toughness (determined by the Charpy V-notch impact test). These are given in Table 1.

Table 1 : Designation of mild steels used for ship structural applications. (Lloyd's Register, 1999)

Grades	A	B	D	E
Chemical Composition(%)				
Carbon	0.21 max.	0.21 max.	0.21 max.	0.18 max.
Manganese	2.5 × C%	0.80 min.	0.60	0.70
Silicon	0.50	0.35	0.10 – 0.35	0.10 – 0.35
Sulphur	0.035	0.035	0.035	0.035
Phosphorus	0.035	0.035	0.035	0.035
Aluminium	-	-	0.015 min.	0.015 min.
Yield stress minimum (N/mm^2)	235	235	235	235
Tensile strength (N/mm^2)	400-520	400-520	400-520	400-520
Charpy V-notch impact energy (longitudinal direction, J)	27 (20°C)	34 (0°C)	41 (-20°C)	-

For completeness, mechanical properties and designations of several high strength steels also used in shipbuilding are provided in Table 2.

Table 2 : Mechanical properties of high strength steels used for ship structural applications. (Lloyd's Register, 1999)

Strength Level and Grades	AH 32, DH 32, EH 32 & FH 32	AH 36, DH 36, EH 36 & FH 36	AH 40, DH 40, EH 40 & FH 40
Yield stress minimum (N/mm^2)	315	355	390
Tensile strength (N/mm^2)	440-590	490-620	510-650
Charpy V-notch impact energy (longitudinal direction, 50mm thickness, J)	31	34	41
Note: Impact tests to be performed for various grades at the following temperatures AH 0°C DH -20°C EH -40°C FH -60°C			

2.2 Aluminium Alloys

The second most commonly used material in shipbuilding after steel is aluminium alloy. The aluminium alloy range is very versatile because of its unique combination of properties for engineering and construction purposes. Aluminium alloys have the primary advantage of being light weight with some alloys having comparable strength to that of structural steel, thus providing better strength to weight ratio compared with steel. They also have high corrosion resistance.

The system of designating aluminium alloys is determined by an international agreement adopted by all major aluminium producing countries, including Australia. Aluminium alloys are designated by both alloying and temper processes used to produce particular desired properties.

Aluminium alloys are classified under two categories: non-heat treatable and heat treatable. The non-heat treatable alloys are those that respond to cold working (rolling/drawing) to improve mechanical properties. The properties are then degraded when heat is applied (for example, from welding). To improve the properties the material would require reworking, which is not always possible. The non-heat treatable alloy series are 1XXX, 3XXX, 4XXX and 5XXX. The heat treatable alloys 2XXX, 6XXX and 7XXX series are those that respond to heat treatment to improve mechanical properties. Welding will reduce the strength of the alloy, however post-heat treatment can restore the strength close to its original properties (Australian Aluminium Council (ACC), 1994).

The mechanical properties of aluminium alloys are varied and this allows versatility when selecting a particular series and grade of aluminium alloy. The aluminium alloy series 1XXX to 7XXX have different applications depending on their major alloying element content as detailed below (Table 3).

Aluminium alloys lose mechanical strength dramatically at elevated temperatures (above 200-250 °C). The melting point for aluminium alloy is around 550 to 600°C and this is why the mechanical properties degrade very quickly at high temperatures. However, the strength of aluminium alloy increases as the temperature is lowered with little reduction in ductility (Table 4).

Table 4 details the mechanical strengths of various aluminium alloys at varying temperatures with an emphasis on 5XXX and 6XXX series (marine series).

Table 3 : Designation of aluminium alloys. (Welding Technology Institute of Australia (WTIA) 1997)

Alloy	Major Alloying Element	Alloy Series	Characteristics
Aluminium	> 99.00% Aluminium	1XXX	Pure aluminium for applications requiring excellent corrosion resistance, high conductivity and good workability - strength & readily weldable.
Aluminium alloys grouped by major alloying element	Copper	2XXX	High strength, low corrosion resistance & difficult to weld by common means (MIG, TIG).
	Manganese	3XXX	Good workability, moderate strength & readily weldable.
	Silicon	4XXX	Melting point lowered without producing brittleness and utilised as filler for welding and brazing.
	Magnesium	5XXX	Moderate to high strength, good corrosion resistance to the marine environment and readily weldable.
	Magnesium & Silicon	6XXX	Moderate strength, good formability, corrosion resistance and readily weldable.
	Zinc	7XXX	High strength, difficult to weld.

Table 4 : Various series of aluminium alloys at a range of temperatures.

Alloy and Temper	Temperature °C	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Elongation in 50 mm (%)
5083-H321	-195	420*	245*	25*
	25	305	215	10
	370	35*	25*	115*
5383 - H321	-195	420*	245*	20*
	25	305	220	10
	370	35*	25*	115*
6082 - T6	-195	415	325	22
	25	310	275	17
	370	20	10	95

(* indicates assumed values)

Advantages of aluminium alloys are:

- Light weight
- Corrosion resistant
- Easily formed
- Easily fabricated
- Readily available
- Ductile
- Non magnetic

Disadvantages of aluminium alloys may be listed as:

- Poor fatigue properties
- Poor performance in fire
- Low melting point and softening temperature
- High relative cost
- Strength and stiffness less than steel

Aluminium alloys are already a very important material in the construction of fast ferries and high speed light craft. The lighter construction of these vessels allows a higher speed or reduced fuel consumption resulting in a reduction of overall running costs.

The properties of 5XXX and 6XXX series aluminium alloys can be compared to other metallic materials commonly used in the marine environment (Table 5).

Table 5 : Comparative properties of material in common use in the marine environment.

Comparative Materials	Density (g cm^{-3})	Melting Point (liquidus) ^0C	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
Al 5086-H116	2.66	600	230	320	10
Al 5083-H116	2.66	600	215	305	10
Al 5383-H116	2.64	600	220	305	10
ALUSTAR-H116	2.66	600	260	360	24
6082-T6	2.66	600	280	315	12
Steel E24	7.8	1450	240	410	40
Stainless Steel 18/8	7.9	1450	280	630	55
Copper	8.9	1083	70	235	45
Copper-Nickel 90/10	8.9	1140	120	320	40
Copper-Alu 6%	8.2	1050	180	400	60
Titanium	4.5	1670	250	380	20

2.3 GRP Composites

A composite material is composed of two or more distinct phases. Fibre-reinforced plastics (FRPs) are one such example of a polymer composite material where glass, aramid or carbon fibres reinforce a matrix of polyester, vinylester or epoxy resin. The properties of various reinforcing fibres and resin materials vary enormously. Data can be obtained from manufacturers (www.spsystems.com) and summaries are available in texts (Smith, 1990). The mechanical properties of a polymer composite are dependent on the properties of the reinforcing fibres (defined by the type and weave of the fibres) and the resin material, and also on the laminate arrangement (volume fraction of reinforcement, fibre alignment and stacking sequence). This is one of the main advantages of polymer composites – the material can be tailored for a specific application. Some properties of commonly used polymer composites are shown in Table 6.

Marine polymer composites may be used in the form of single-skin (eg., RAN Minehunter Coastals) or sandwich construction. Sandwich construction incorporates a core material such as PVC (poly vinyl chloride) foam bonded between FRP skins. Examples of sandwich construction include the hull structures of the RAN Minehunter Inshore (MHIs), Skjold class Fast Patrol Boat (Norway), Visby class Corvette (Sweden) and superstructures of the Rauma 2000 Fast Attack Craft (Finland) and La Fayette Frigate (France).

A typical marine-grade glass-reinforced plastic (GRP) laminate has a density of approximately 1.7 t/m^3. However, the overall weight of a GRP structure is dependent on constraints that may influence stiffener layout etc, and also the desired combination of strength and stiffness. Typically, GRP structures are lighter than equivalent steel structures. For example, the structural weight of a 52m patrol craft with an optimal steel and GRP structure has been calculated to be 114 tons and 72 tons, respectively (Goubalt and Mayes, 1996).

Advantages of GRP composites over steel and other metals may be identified as:

- Low magnetic properties
- Low electrical conductivity (glass-reinforced plastics)
- Resistance to corrosion
- Resistance to rot and marine growth
- Relatively high sonar transparency
- Good strength to weight ratio
- Good fatigue properties[1]
- Maintenance of properties at low temperatures
- Availability
- Can be manufactured to near net-shape

[1] dependent on joint design.

- Stiffness and strength can be tailored to structural requirements
- Excellent thermal insulation
- Light weight

Shear strength between lamina (inter-laminar shear strength) is often cited as a weakness of GRP composite materials. However, appropriate design and application can avoid potential delamination problems. In general, disadvantages of GRP may be listed as:

- Low inter-laminar strength
- High dependence on construction quality assurance
- Low inherent stiffness
- Susceptible to fire damage

Table 6 : Typical mechanical properties of FRP laminate, from Smith (1990).

Material	Fibre Volume Fraction V_f	Specific Gravity (SG)	Young's Modulus E (GPa)	Shear Modulus (GPa)	Tensile Strength σ_{UT}(MPa)	Comp. Strength (MPa)	Shear Strength (MPa)
E-glass polyester (CSM)	0.18	1.5	8	3	100	140	75
E-glass polyester (balanced WR)	0.34	1.7	15	3.5	250	210	100
E-glass polyester (unidirectional)	0.43	1.8	30	3.5	750	600	
Carbon/epoxy (high strength balanced fabric)	0.5	1.5	55	12	360	300	110
Carbon/epoxy (high strength unidirectional)	0.62	1.6	140	15	1500	1300	
Carbon/epoxy (high modulus unidirectional)	0.62	1.7	300	20	700	650	
Kevlar 49/epoxy (unidirectional)	0.62	1.4	50	8	1600	230	

GRP composites have been used for several naval applications, including the Minehunter Inshore (MHIs) and Huon class Minehunter Coastal (MHCs) vessels and bow sonar dome and casing to the Collin class submarines in Australia. Mine counter measure vessels overseas including the Hunt and Sandown classes in the UK, Osprey class in the US and the Gaeta class of Italy are also GRP construction. Other marine applications of FRPs have included patrol boats, corvettes, superstructures, propellers and appendages of surface vessels.

There are two main fabrication processes available for GRP shipbuilding: hand lay-up and the SCRIMP method. Hand lay-up is a well established technique and has been used successfully for the Huon class minehunters. SCRIMP is a registered trade name for a method known as Vacuum Assisted Resin Transfer Moulding (VARTM). This method can provide higher fibre-resin ratios, and hence mechanical properties, than the hand lay-up process. VARTM has become a well-established technique and has been used for the Type II Sandown class minehunter in the U.K and is proposed for the USN DDG 21 Helo Hangar which are of sandwich construction.

3. Design, Construction and Through-Life Related Issues

The replacement patrol boats will be designed and built to civilian classification rules. In the following section the effects of different material selection on design, construction and through life operation will be discussed. Issues include:

- Classification
- Construction
- Operation
- Cost
- Repair, inspection and maintenance
- Hull degradation

3.1 Classification

All of the major classification societies have developed rules that cover steel, aluminium alloy and GRP construction. Over the years, they have gained extensive experience with steel construction. Classification societies such as Det Norske Veritas (DNV) and Lloyd's Register of Shipping (LR) have also gained great experience on aluminium fast ferry design and construction. For example, the RAN has operated HMAS Jervis Bay with DNV classification. GRP composite materials have been extensively used in small boat building. Despite not all vessels requiring class registration, all major classification societies have experience in classing FRP/GRP composite boats. Therefore, it is believed that the use of any of the three materials considered will not present significant difficulties in terms of classification.

The classification society rules mentioned above generally relate to merchant vessels operating in the commercial environment. However the specification for the replacement patrol boat will require some characteristics which relate to the military environment, for example issues relating to magazine safety. In this specific example reference should be made to AO16437. This document suggests that the construction material for magazine boundaries, including doors and hatches, shall be watertight to an extent which is consistent with overall vessel design and constructed from steel.

Alternative materials may be used so long as a competent authority approves the explosive ordinance performance characteristics. In fact such an approach has been used for the MHC magazine boundaries (Bocksteiner et al., 2000). In future acquisitions the classification society could be regarded as the competent authority (ABR5454). In this case the RAN will turn to such societies to approve the design and construction of such spaces. A class certificate will not be issued until equivalent safety measures to that of the steel structure are in place. Many of the concepts will come from the relevant warship rules each classification society current has.

3.2 Construction

Another issue that must be taken into consideration is whether local expertise exists in building ships using these materials.

Although Australia does not have a large commercial steel shipbuilding industry, ships of different sizes and types including naval ships are built in Australia. Tenix Defence Systems in Melbourne are currently building the RAN ANZAC class frigates, which are of steel construction. The Fremantle class patrol boats were also built in Australia using steel.

The use of aluminium alloys in the fast ferry industry has had a long and successful record. The problems experienced with its use in the marine environment have been overcome. Undoubtedly, Australia is the world leader in aluminium fast ferry construction. One such example is HMAS Jervis Bay that was designed and built by International Catamarans (INCAT). Another example is the vessels built by Austal Ships Pty for the Australian Customs Service. Although aluminium alloy vessels have not been built specifically for naval applications, experience gained in design, construction and maintenance of these vessels is equally applicable to a patrol boat design and construction.

Within the local marine industry, the use of GRP composites for commercial and private high speed small craft is well established. The Queensland Department of Transport has shown the initiative in establishing regulations and future needs for high speed craft in Australia (up to 35 m). Australian Defence Industries (ADI) has considerable experience in the construction and maintenance of GRP vessels as demonstrated by the Huon Class MHCs. The RAN and DSTO also have experience from acquiring and operating the MHI (sandwich construction) and MHC (single skin GRP construction) fleets.

3.3 Operation

A ship of the same size built from an aluminium alloy or GRP composite is expected to be lighter than an equivalent vessel built with steel. It is expected that the seakeeping performance of the lighter hull will be somewhat worse than that of the heavy vessel.

To ascertain a quantitative variation in seakeeping performances between a heavy and light hull, seakeeping analyses for two generic replacement patrol boats were carried out by the using two-dimensional strip theory numerical prediction code, SHIPMO7. The two generic replacement patrol boat hulls considered in the analyses have the same geometry but one is chosen to be 5 percent lighter (representing an Aluminium or a GRP composite hull) than the other (representing a steel hull).

From these analyses, the transverse, longitudinal and vertical displacements, velocities and accelerations were obtained for the vessels travelling at forward speeds of 5, 12 and 25 knots in sea states ranging from Sea State 2 to Sea State 7. These motions were determined at two positions (longitudinal centre of gravity (LCG) and the bow) along the length of the vessels. Motion Induced Interruptions (MIIs) in the lateral and longitudinal directions and the total MIIs were also calculated. A selection of the results is given in Tables 7-10.

As can be seen from Tables 7 and 8, both the LCG and bow vertical accelerations for the light generic RPB were slightly larger than those obtained for the heavy generic RPB, but the differences were in general less than 1 percent. Similar trends were also observed for the lateral, longitudinal and total MIIs (Tables 9 and 10), but the variation in some cases was about 5 percent for sea states 4 and 5. It is interesting to note that the risk level associated with MII values of 5 and above is considered to be extreme. The risk associated with the operation of a craft in terms of seakeeping and structural integrity is currently being investigated by DSTO (Cannon et al., 2000).

Table 7 : RMS values of vertical accelerations (g) at LCG for the heavy (RPB(H)) and light (RPB(L)) generic replacement patrol boats travelling in irregular seaways.

Ship Speed		**25 knots**		**12 knots**		**5 knots**	
Position	**LCG**	**Vert. Acceleration (g)**		**Vert. Acceleration (g)**		**Vert. Acceleration(g)**	
Sea State	**SWH (m)**	**RPB (H)**	**RPB (L)**	**RPB (H)**	**RPB (L)**	**RPB (H)**	**RPB (L)**
SS 2 (top)	**0.500**	0.024	0.024	0.024	0.024	0.024	0.024
SS 3 (mean)	**0.875**	0.070	0.071	0.044	0.044	0.044	0.044
SS 3 (top)	**1.250**	0.109	0.109	0.060	0.060	0.051	0.051
SS 4 (mean)	**1.875**	0.150	0.151	0.076	0.077	0.060	0.060
SS 4 (top)	**2.500**	0.181	0.182	0.084	0.084	0.064	0.063
SS 5 (mean)	**3.250**	0.226	0.227	0.103	0.103	0.078	0.077
SS 5 (top)	**4.000**	0.249	0.250	0.111	0.111	0.082	0.082
SS 6 (mean)	**5.000**	0.264	0.264	0.115	0.115	0.085	0.085
SS 6 (top)	**6.000**	0.268	0.268	0.116	0.116	0.086	0.085
SS 7 (mean)	**7.500**	0.286	0.286	0.125	0.125	0.091	0.091

Table 8 : RMS values of vertical accelerations in (g) at the bow for the heavy and light Generic Replacement Patrol Boats travelling in irregular seaways.

Ship Speed		**25 knots**		**12 knots**		**5 knots**	
Position	**Bow**	**Vert. Acceleration (g)**		**Vert. Acceleration(g)**		**Vert. Acceleration(g)**	
Sea State	**SWH (m)**	**RPB (H)**	**RPB (L)**	**RPB (H)**	**RPB (L)**	**RPB (H)**	**RPB (L)**
SS 2 (top)	**0.500**	0.04	0.042	0.050	0.051	0.046	0.047
SS 3 (mean)	**0.875**	0.164	0.167	0.137	0.138	0.102	0.102
SS 3 (top)	**1.250**	0.241	0.244	0.170	0.171	0.120	0.121
SS 4 (mean)	**1.875**	0.355	0.357	0.212	0.213	0.139	0.139
SS 4 (top)	**2.500**	0.413	0.415	0.235	0.235	0.143	0.143
SS 5 (mean)	**3.250**	0.511	0.513	0.289	0.289	0.173	0.173
SS 5 (top)	**4.000**	0.552	0.553	0.308	0.309	0.179	0.180
SS 6 (mean)	**5.000**	0.57	0.571	0.316	0.317	0.180	0.181
SS 6 (top)	**6.000**	0.569	0.570	0.314	0.315	0.177	0.178
SS 7 (mean)	**7.500**	0.597	0.597	0.329	0.330	0.186	0.187

Table 9 : Lateral, longitudinal and Total Motion Induced Interruptions (MIIs) per minute at LCG for the heavy and light Generic Replacement Patrol Boats travelling in irregular seaways.

Ship Speed	**25 knots**	**Lateral MIIs**		**Long. MIIs**		**Total MIIs**	
Position	**LCG**						
Sea State	**SWH (m)**	**RPB (H)**	**RPB (L)**	**RPB (H)**	**RPB (L)**	**RPB (H)**	**RPB (L)**
SS 2 (top)	**0.500**	0.000	0.000	0.000	0.000	0.000	0.000
SS 3 (mean)	**0.875**	0.002	0.002	0.000	0.000	0.002	0.002
SS 3 (top)	**1.250**	0.164	0.175	0.000	0.000	0.164	0.175
SS 4 (mean)	**1.875**	0.974	1.021	0.022	0.027	0.974	1.021
SS 4 (top)	**2.500**	1.464	1.543	0.189	0.191	1.464	1.543
SS 5 (mean)	**3.250**	3.722	3.803	0.976	0.984	3.812	3.895
SS 5 (top)	**4.000**	5.313	5.405	1.583	1.593	5.468	5.563
SS 6 (mean)	**5.000**	6.309	6.411	1.995	2.007	6.495	6.601
SS 6 (top)	**6.000**	6.543	6.654	2.099	2.114	6.719	6.834
SS 7 (mean)	**7.500**	7.512	7.637	2.672	2.692	7.784	7.915

Table 10 : Lateral, longitudinal and Total Motion Induced Interruptions (MIIs) per minute at the bow for the heavy and light Generic Replacement Patrol Boats travelling in irregular seaways.

Ship Speed	25 knots	Lateral MIIs		Long. MIIs		Total MIIs	
Position	Bow						
Sea State	SWH (m)	RPB (H)	RPB (L)	RPB (H)	RPB (L)	RPB (H)	RPB (L)
SS 2 (top)	**0.500**	0.000	0.000	0	0.000	0	0.000
SS 3 (mean)	**0.875**	0.115	0.135	0.001	0.002	0.117	0.137
SS 3 (top)	**1.250**	1.362	1.461	0.254	0.272	1.509	1.616
SS 4 (mean)	**1.875**	4.698	4.913	2.666	2.711	5.427	5.654
SS 4 (top)	**2.500**	7.247	7.478	4.435	4.470	8.214	8.456
SS 5 (mean)	**3.250**	11.938	12.200	7.627	7.688	14.864	15.097
SS 5 (top)	**4.000**	13.537	13.785	8.775	8.847	17.906	18.143
SS 6 (mean)	**5.000**	14.130	14.364	9.212	9.283	19.29	19.514
SS 6 (top)	**6.000**	13.984	14.212	9.073	9.137	19.189	19.4
SS 7 (mean)	**7.500**	14.827	15.049	9.805	9.877	21.065	21.284

The accumulation of marine fouling on a hull can cause a reduction of the maximum service speed and lead to increased fuel costs. This is an issue for vessels constructed with steel, aluminium alloy or GRP composite material and requires the application of an antifouling paint system to combat the problem. The Navy currently uses self-polishing copolymer systems which continuously release tributylin (TBT) and other antifouling biocides to prevent fouling settlement and attachment. However, the application of TBT coatings is likely to be banned ahead of the RPB coming into service.

For a steel or GRP hull the most likely replacement antifouling coating in the short to medium term will be a copper-based self polishing coating. Patch trials have demonstrated that these coatings can provide 4 years effective fouling protection on patrol boats under current operational profiles. Copper based coatings are not suitable for a hull constructed of aluminium alloy. The best biocidal alternatives provide up to 2 years antifouling protection. Alternatively, more expensive silicone fouling release coatings are capable of longer term protection. For example, a trial on a FCPB provided protection for the duration of the standard 4 year docking cycle. This type of system has also been applied to HMAS Jervis Bay.

A GRP composite vessel also requires installation of a conducting grid to act as a ground plane for radio antennas, metallic plates low in the hull for electrical earthing, and screening of compartments containing significant electronic equipment to obtain electromagnetic compatibility and minimal interference. Procedures for each of these requirements are well established.

3.4 Cost

It is difficult to compare costs for a generic structure. When estimating the cost of a platform it is important to consider the overall through life cost of the platform, which is related to both the initial and the operational costs. The resale value of the platform should also be considered when its service is no longer required.

A previous study concluded that the initial cost of a GRP composite patrol boat structure was higher than for steel but total ship cost and lifecycle costs were comparable (Table 11).

Table 11 : Cost comparison for a patrol boat, from Goubalt and Mayes (1996).

	Steel Design	GRP Design
Displacement (ton)	341	267
Length (m)	51.82	51.82
Installed Power (HP)	13650	11400
Fuel weight (ton)	36.3	30.8
Structure Weight (ton)	113.7	73.5
Structure Cost (US$M)	1.00	1.31
Total Ship Cost (US$M)	21.1	20.7
Life-Cycle Cost (US$M)	93.2	87.3

Another comparative study on the structural design of a fast ferry built from aluminium alloy and GRP composite showed that a GRP composite ship realised a 32 per cent saving in structural weight or 13 per cent saving in total displacement (Hughes, 1997). This weight saving could provide about a 12 per cent reduction in fuel costs.

As expected, weight is one of the most critical factors in determining the cost of a platform. It is almost certain that the use of steel will result in the heaviest structure with the highest fuel costs, though the initial cost may be lower due to the relative low cost of steel compared with other materials.

In terms of resale value of a platform, hull deterioration will be the determining factor. Steel corrodes easier than aluminium alloys whereas GRP composite does not corrode, and therefore it is anticipated that the resale value of a steel platform will be less than that of aluminium alloy and GRP composite platforms for a given service life expectancy. On the other hand, an aluminium alloy hull structure may have a less resale value due to its shorter fatigue life. Information on the resale value of a GRP composite hull of this size and type is not currently available.

3.5 Repair, Inspection and Maintenance

Steel hull construction requires greater attention in terms of inspection, maintenance and repair due to its weakness against corrosion. Ship structural steels are always

prone to corrosion, and it is particularly important in terms of design to give considerations for easy protection and preservation from the effects of salt water and high humidity. Nevertheless, inspection, maintenance and repair techniques for steel structures are well established and are in use by the RAN.

The second most frequent cause for structural deterioration in service is fatigue. Although fatigue is an issue for steel structures, its consequences are relatively well understood and can be managed without much difficulty. However, fatigue of aluminium alloy structures is a more serious problem. Therefore, inspection and maintenance procedures of an aluminium alloy hull become more critical. There is a significant body of knowledge on how to manage fatigue of aluminium alloy hulls, particularly from the high speed craft industry. From the RAN perspective, limited knowledge has been gained in the operation of HMAS Jervis Bay. This vessel has been maintained in class by DNV and INCAT and has not caused any significant impact on the RAN operations.

The response of GRP composites to fatigue is also well understood. The fatigue damage tolerance of GRP composites is high. Initial fatigue damage occurs in the form of resin cracking and fibre de-bonding as the fibre reinforcements redistribute stress and arrest crack propagation through the laminate. Propagation of a through thickness crack to cause panel failure is accepted to be highly unlikely for this reason (Smith, 1990). This view is supported by the service performance of GRP vessels in the Royal Navy such as HMS Wilton and the Hunt class minesweepers. Fatigue is usually only a concern in structural connections (eg. bulkhead to hull joints) where the adhesive bond, rather than the GRP laminate, may fail.

GRP composite materials do not require significant maintenance. Typical marine fibre-resin systems are resistant to UV radiation. Established schemes exist for the application of paint coatings where desired. Sub-surface delamination can occur if a component is overloaded. Such a delamination may not propagate under normal loading conditions but may be critical for subsequent overloading events. These defects can be reliably detected in single-skin GRP using ultrasonics. Tap testing is most commonly used to detect delamination in a GRP sandwich composite although it is not a particularly reliable or accurate technique. Ultrasonics can then be used to determine if a delamination is present in one of the skins. However, reliable NDE techniques for assessing the integrity of the skin-core interface and the core itself are still under development.

Fracture or delamination is usually repaired by cutting around the damaged region and re-laminating to retrieve a continuous laminate (Mouritz et al., 2000). A more recent technique involving resin infusion may also be used. This has been demonstrated by DSTO on HMAS Hawkesbury (MHC) and also shown to be effective for repairing bulkhead to hull T-joints. Complete restoration of mechanical performance can be obtained for repairs involving cut-out and re-lamination and also for repairs using the resin-infusion technique.

3.6 Hull Degradation

The exterior and interior of a steel ship structure will corrode if protective measures are not taken. Protective paint coatings can be used successfully to delay the onset of corrosion, and, if maintained appropriately, to minimise corrosion during the operational life of a vessel. Issues to consider are appropriate coating selection, application and inspection frequency and technique. Most protective coatings currently in use are a form of two-part epoxy, although several types are available. Classification societies, with the cooperation of coating manufacturers, offer a range of coating selections for different ship spaces that will provide protection for a given period of time, typically five or ten years. However, estimated coating lifetimes are conditional on a substrate being exposed to the intended environment.

DSTO has extensive experience in protective coating technology. Investigations of the steel hull Fremantle Class Patrol boats has determined that corrosion is essentially inside-out, and arises largely from design limitations, inadequate internal paint thicknesses and access difficulties. It is considered that adoption of the new increased paint thicknesses specified for internal areas of RAN vessels and use of non-corroding materials in impact areas would permit a steel hull construction to meet 5 year docking schedule as required by classification society guidelines.

Cathodic protection may also be used to reduce the effects of corrosion on a steel hull structure. The use of sacrificial anodes, as opposed to impressed current, is the most common method and has been used on naval and commercial vessels for many years. However, this is only applicable to the underwater region of external hull plating and also to ballast tanks. The latter application is only effective at protecting exposed areas of steel when a tank is ballasted – corrosion will proceed when a tank is empty. DSTO has significant experience in cathodic protection methods.

Aluminium alloys are more corrosion resistant than steel. Nevertheless, corrosion can occur and therefore protective coatings and cathodic protection are also necessary for aluminium alloy ship structures. Both technologies, as for steel vessels, are well established. The demands on coating and sacrificial anodes on aluminium alloy ships are considerably less than for steel vessels.

Although corrosion protection measures can be applied to steel vessels, classification society rules still incorporate a corrosion margin in the initial scantlings. This results in increased weight and remains a disadvantage compared to aluminium alloy and GRP composite construction. Furthermore, due to their dependency on corrosion protection measures, inspection and maintenance of steel hull vessels in particular (although still necessary for other materials) must be emphasised. This tends to increase the through-life costs of steel construction compared with aluminium alloy and GRP composite constructions.

GRP composites have excellent corrosion resistance. They do not corrode in the presence of seawater or moist air. However, stiffness, strength and fatigue resistance can be reduced due to water absorption. For a specimen at saturation through the thickness, compressive strength can decrease by up to 30%. Tensile strength is affected less and stiffness is generally not affected. The influence of this phenomenon is dependent on paint coating application, panel design, location, immersion time, seawater temperature and the load condition. For typical panel thicknesses' used in shipbuilding it may take 20-30 years or even longer for water absorption to occur to saturation level. It is of some relevance that durability tests were performed by the Defence Evaluation and Research Agency on the Hunt class minehunter operated by the Royal Navy after 20 years of service. From this it was decided to extend the life of the vessel to 40 years. In the case of GRP sandwich composites, where face laminate thickness is usually lower than a single-skin laminate, failure is often governed by the shear response of the core material in which case a possible reduction of in-plane strength of the skins due to water absorption may not be critical.

4. Military Issues

The Replacement Patrol Boats (RPBs) are designed to commercial standards with the primary role of the platform being patrol and surveillance as specified in RPB Ship Specification Document. The RPBs are not intended to engage in hostile 'war-fighting' situations as the platform will not be designed or equipped to fulfil this role effectively. Nevertheless, the following information is provided for discussion purposes.

Military issues in naval platform structures can be divided into two areas - detection avoidance and damage mitigation. Firstly, detection avoidance is of prime importance when a platform enters a hostile situation. Detection by an 'unfriendly' platform or weapon can be from an active or passive device. Active detection will use the reflected radar signature of the platform and passive detection uses the radiated infra-red or magnetic signatures. Secondly, damage mitigation considerations are important in the event that a weapon has detonated and damaged the platform. This could be due to a number of weapons such as an anti-ship missile, gun projectile, underwater torpedo or mine. In such cases the vulnerability of the platform must be considered. The platform must be designed so that minimum weapon damage to the structure and systems occur. Fire resistance is also a consideration. These issues are discussed below.

4.1 Radar Signature

All metals are highly reflective to radar, therefore, in addition to design shape considerations, both steel and aluminium alloy structures will need to utilise Radar Absorbing Material (RAM) to reduce the signature. This can be applied by a resistive coating or panel on the surface of the structure or by using portable nets which can be

draped over the exposed panels to reduce the radar signature. Extensive research is being conducted both in Australia (DSTO) and overseas.

GRP composite panels offer advantages in terms of maintaining initial "flatness" which assists with reducing radar signature. However, they are also relatively transparent to electromagnetic radiation and therefore it is possible that metallic components within a hull can enhance radar reflection. Nevertheless, load-bearing laminates can be designed to have a significantly reduced effective radar signature compared to metallic materials. Such laminates are referred to as structural RAM and have been tested in Australia (DSTO) as well as overseas. Continued development is likely, particularly with the general trend towards developing GRP composite superstructures.

4.2 Magnetic Signature

The magnetic signature is important in situations where the platform has entered an underwater mine field. Particular mines can detect the change in the magnetic field as the platform passes nearby thus leading to a detonation. The hull material is important in this case. Steel is highly magnetic and it requires high degaussing energies to reduce the signature. Degaussing is used in steel hull naval ships, however, there will still be some magnetic signature remaining. Aluminium alloy is non-magnetic, however, it is highly conductive and eddy currents can still raise the magnetic signature. GRP composites have a low magnetic signature, hence their use in mine-countermeasure vessels.

4.3 Infra –red Signature

Both steel and aluminium alloys have a high thermal conductivity, therefore thermal leakage to external surfaces is of high importance. This can be minimised using thermal insulation to reduce heating of the exposed surfaces. Alternatively, GRP composites have very low thermal conductivity, approximately 1-2 per cent of that for mild steel and less than 1 per cent for aluminium alloys.

4.4 Vulnerability and Fire Resistance

The vulnerability of a ship is the functionality of the platform following an impact and detonation by munitions. Much of the vulnerability of a particular platform is dependent on the munition size, structural design and the redundancy of the systems on board. Construction material type is an issue when considering impact of the projectile or the detonation fragments and blast. Both steel and aluminium alloys are damage resistant materials. Steel, with a higher strength and higher toughness, is more resistant to projectile penetration from blast fragments and small weapons fire and can also withstand higher blast pressures compared to aluminium alloys. Per unit thickness, steel has a much greater fragment stopping power and a greater blast resistance. This has relevance for protection against small arms incidences and shoulder launched missiles that could result from incursions into Australian waters.

A measure of the vulnerability of the platform from missile detonation and small projectiles depends not only on the material of construction but also on the structural design and systems layout. A platform with relatively small compartments will be less vulnerable, and thus be more effective in containing the detonation, than large compartments in the same space. Conversely, the vulnerability of the platform will be decreased where critical systems are closely packed compared to system design where there is redundancy. In the final design of the RPBs adequate protection of small arms lockers and vital spaces should also be considered (Buckland et al., 1999).

GRP generally has comparable impact strength to other structural materials although it can vary according to laminate specification. With regard to ballistic impact, GRP compares well, particularly for small arms attack and high velocity fragments from exploding missiles (Smith, 1990). Short duration loads arising from vibration, shock or impact, induce high strain rates. Marine GRP maintains equivalent or slightly improved in-plane mechanical properties under high strain rate tests compared to static test results (St John et al, 2000).

Varying degrees of fire resistance are afforded by each material. Steel is a non-combustible material and is therefore fire resistant. Its only shortcoming is that it has a high thermal conductivity and therefore the transfer of heat to adjacent compartments can be high.

Aluminium alloys are also non-combustible. However, they do have a relatively high thermal conductivity and low melting point. This can lead to structural failure in the event of a fire. Protection measures may therefore have to be considered for an aluminium structure.

GRP composite materials are combustible. The main effects of combustion are material degradation leading to reduced strength and the release of heat, smoke and volatiles. However, due to the low thermal conductivity of GRP the potential for a fire to spread is reduced compared with metallic structures. For example, an engine room fire aboard the GRP Royal Navy minehunter HMS Ledbury was reported to reach 650°C and left to burn for four hours with no damage to adjacent compartments and no requirement for boundary cooling (Bocksteiner et al., 2000). For protection in critical areas thermal barrier materials are an option. For example, they have been tested successfully by DSTO for application to GRP munition magazines (St John et al., 2000).

5. Summary

The main characteristics of steel, aluminium alloys and GRP composite materials have been outlined in relation to the construction, maintenance and military operation of a patrol boat type platform. In order to achieve the required capability and preparedness of a platform constructed in either material it is most important that appropriate inspection, maintenance and repair procedures be implemented. Such procedures are well established for steel vessels operating in the RAN. Appropriate inspection, maintenance and repair procedures have also been implemented for RAN vessels constructed in aluminium alloy (HMAS Jervis Bay) and GRP composites (MHI fleet). The inspection, maintenance and repair procedures for the MHCs are now being formulated. Some guidance is given in relation to the cost of a patrol boat craft constructed in each material. In this regard it is important to consider both the initial and operational costs and also the resale value of a platform.

Many of the issues raised in this report are the subject matter of research and development tasks currently being undertaken by the Maritime Platforms Division (MPD), DSTO. Details of the tasks are outlined in Appendix A.

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Appendix A: Relevant DSTO Tasks

The table below provides details of the research and development tasks which are relevant to the Replacement Patrol Boat program, currently being undertaken by the Maritime Platforms Division, DSTO.

Task Number	Task Title	Task Manager	Task Sponsor
NAV 98/054	MHC Platform Integrity	Dr P Burchill	DNPS
NAV 00/169	Capability Management: Surface Ship Structures	Dr S. Cannon	COMAUSNAV-SURFGRP
NAV 97/120	Low Observability of Naval Platforms	Dr P. Jewsbury	DGNC
NAV 98/068	Fire Modelling for Naval Platforms	Dr S. Kennett	CSO (W)
NAV 99/086	Advanced Paint and Primers for Naval Vessels	Dr L. Wake	DGNAVSYS
NAV 99/105	Corrosion Control for Navy Platforms	Dr P. Mart	DGNAVSYS

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19. ABSTRACT

This technical note considers the main characteristics of steel, aluminium alloys and glass fibre-reinforced composite materials in relation to the selection of primary structure for patrol boat type platforms. It is not intended to recommend or rank the suitability of candidate materials, but rather to note the main properties of each material and outline some practical considerations in relation to the construction, maintenance and military operation of patrol boats constructed from these materials.